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Experimental Investigation of Ultrasonic Welding on Non-metallic Material

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Abstract

In the present scenario of developing plastic utility in engineering applications, demand for reliable and faster joining processes has increased. Ultrasonic welding of thermoplastic is one of those joining methods which is based on application of high-frequency vibratory energy in that work pieces are held together under pressure without melting. Ultrasonic welding of thermoplastic composites has become an important process in industry because of its relatively low cost and high quality resultant joints. This study involves modelling of experimental data of joint strength of acrylonitrile butadiene styrene (ABS) material for ultrasonic welding on welding parameters (welding pressure, welding time, amplitude). In order to determine critical states of the welding parameters, analysis of variances has applied while optimisation of the parameters affecting the joint strength has achieved with centre composite method of the Response Surface Methodology.

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Keywords: Ultrasonic welding; ABS; Design of experiments (DOE); ANOVA; Response surface method (RSM); Centre composite.

1. Introduction

Due to higher surface finish, high impact strength, higher moulding capability of thermoplastic material, use of thermoplastic material has increased compared to thermosetting material in modern components [1]. There are several methods available for welding the plastic materials, like hot gas welding, friction welding, ultrasonic welding (USW), and laser welding etc. Till now most of research is done for USW on the metals and on some plastic only. So here ABS is chosen for the research because of its wide usage. ABS material can also be welded by laser transmission welding and friction stir welding [2, 3]. This material is used in automotive components like in flood lights, looking mirror, dashboard components, displays and cabinets and cell phone assemblies to name a few of their many applications. Usually in automobile industries the parts which are made of ABS material are welded by ultrasonic welding.

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Mostly, plastic materials are joined by ultrasonic welding method because of the advantage of very less welding time [4]. Quality of weld not only depends on welding technique but also depends on property of welding materials. Ultrasonic welding is a solid state welding process. It is basically a joining process of similar or dissimilar metallic / nonmetallic material. Here the joint produced is by the application of the high frequency vibratory energy in the work pieces held together under pressure without melting [5]. Major factors affecting the welding strength are welding pressure, welding time and amplitude [6-10].

2. Experiment

2.1 Experimental setup

The experiments have done on the plastic ultrasonic welding machine (USP 3000-3000). The specification of the machine is shown in the table 1. The actual experimental setup is as shown in fig. 1. Here in the machine the horn is made of titanium alloy and anvil is made of steel material. The booster having gain factor 2 and horn having a gain factor 1 that helps for achieving require amplitude range.

Table 1 Ultrasonic machine specification.

	Values
Input power	3000 W
Output frequency	20 kHz
Maximum amplitude	100 %
Maximum force	3000 N
Stroke length	100 mm



Fig 1 Experimental setup.

2.2 Factors influencing the weldability

There are mainly two types of factor that affect any process one is the controlled and another is uncontrolled one. Here in the USW, the controlled factors are welding time, welding pressure, input power, frequency, amplitude etc. The uncontrolled factors are that factors which can't be controlled during process. In this paper, the uncontrolled factors were neglected and controlled factors were selected for study. It has noted that most affecting parameters were welding time, welding pressure and amplitude of sonotrode. The value of amplitude is in percentage. Here 40 μ m is equal to the 100 %. Here all three factors were considered. Each of the factors with three levels has taken as shown in table 2.

Table 2 factors and their levels.

No	Factor	Description	Level 1	Level 2	Level 3
1	Weld pressure (bar)	A	1	1.5	2
2	Weld time (sec)	B	1	1.25	1.5
3	Amplitude (%)	C	70	80	90

2.3 Methodology

In this research work the specimen has prepared according to ASTM standard (D 638-02a) [11]. The specimen selected for the experiment is ABS material having (150 \times 200 mm) and 3 mm thickness. Total 20 run have identified

after applying design of experiment with 3 input parameters and 3 levels. Here the joint strength has measured by universal testing machine as one output parameter. During the tensile testing, ductile fracture has observed at weld interface for most of the welded samples. Analysis of variance (ANOVA) has used to identify significant effect of parameters and regression analysis have to follow to optimize parameter values for maximum joint strength.

3. Result and discussion

Identified 20 runs to experiment, using centre composite technique of response surface method. Designs of experiment have performed and corresponding joint strength have recorded. These experimental runs have allowed estimating the linear and interactive effects of the process parameters on the response parameters. Statistical software Design-Experts [12] was used to code the variables and to establish the design matrix in Table 3.

Table 3: Design matrix and measured experimental results.

Std	Run	Block	Factor 1 A:Weld Pressure bar	Factor 2 B:Weld Time Sec	Factor 3 C:Amplitude %	Response 1 Joint Strength MPa
12	1	Block 1	1.50	1.67	80.00	3.10
4	2	Block 1	2.00	1.50	70.00	5.03
20	3	Block 1	1.50	1.25	80.00	5.40
7	4	Block 1	1.00	1.50	90.00	4.00
14	5	Block 1	1.50	1.25	96.82	6.05
6	6	Block 1	2.00	1.00	90.00	5.10
17	7	Block 1	1.50	1.25	80.00	5.44
1	8	Block 1	1.00	1.00	70.00	3.42
18	9	Block 1	1.50	1.25	80.00	5.40
19	10	Block 1	1.50	1.25	80.00	5.40
15	11	Block 1	1.50	1.25	80.00	5.40
5	12	Block 1	1.00	1.00	90.00	4.86
16	13	Block 1	1.50	1.25	80.00	5.40
10	14	Block 1	2.34	1.25	80.00	4.32
11	15	Block 1	1.50	0.83	80.00	3.65
8	16	Block 1	2.00	1.50	90.00	5.48
13	17	Block 1	1.50	1.25	63.18	3.80
2	18	Block 1	2.00	1.00	70.00	4.25
9	19	Block 1	0.66	1.25	80.00	4.76
3	20	Block 1	1.00	1.50	70.00	5.25

3.1 Analysis of Variance (ANOVA) for Tensile strength

The results of analysis of variance (ANOVA) for joint strength of USW are shown in Table 4. A low P-value (≤ 0.05) indicates statistical significance for the source on the corresponding response (i.e., $\alpha = 0.05$, or 95% confidence level), this indicates that the obtained models are considered to be statistically significant, which is desirable; as it demonstrates that the terms in the model have a significant effect on the response.

Final Equation: Joint Strength = $+5.39 + 0.12 * A + 0.088 * B + 0.39 * C - 0.21 * A^2 - 0.62 * B^2 - 0.073 * C^2 + 0.024 * A * B + 0.14 * A * C - 0.39 * B * C$

Table 4: Analysis of variance.

Source	Sum of squares	DF	Mean square	F value	Prob > F	
Model	9.55	9	1.06	3.20	0.0420	Significant
A	0.19	1	0.19	0.56	0.4720	
B	0.11	1	0.11	0.32	0.5835	
C	2.04	1	2.04	6.15	0.0326	
A ²	0.63	1	0.63	1.90	0.1983	
B ²	5.55	1	5.55	16.76	0.0022	
C ²	0.076	1	0.076	0.23	0.6415	
AB	4.513E-003	1	4.513E-003	0.014	0.9094	
AC	0.15	1	0.15	0.46	0.5108	
BC	1.19	1	1.19	3.60	0.0869	
Residual	3.31	10	0.33			
Lack of fit	3.31	5	0.66	2483.87	<0.0001	significant
Pure error	1.333E-003	5	2.667E-004			
Cor total	12.86	19				

The Model F-value of 3.20 implies that the model is significant. There is only a 4.20% chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case C, B² are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The "Lack of Fit F-value" of 2483.87 implies the Lack of Fit is significant. There is only a 0.01% chance that a "Lack of Fit F-value" this large could occur due to noise, Significant lack of fit is bad.

Std. Dev. 0.58, R-Squared 0.7424, Mean 4.78, Adj R-Squared 0.5106, C.V. 12.05, Pred R-Squared -1.0336, PRESS 26.16, Adeq Precision 5.769. A negative "Pred R-Squared" implies that the overall mean is a better predictor of your response than the current model. "Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 5.769 indicates an adequate signal. This model can be used to navigate the design space.

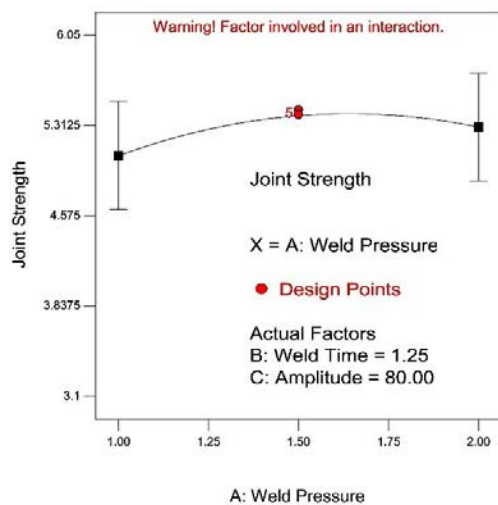


Fig 2 (a): One factor Effect –Weld Pressure

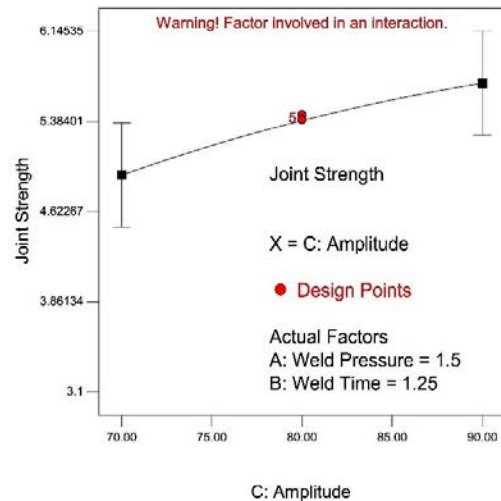


Fig 2 (b): One factor Effect –Amplitude

Fig. 2(a-b) has shown individual effect of weld pressure and amplitude. Referring to table 4, amplitude has identified as most significant parameter with highest value of 'F' is 6.15. The same results have reflected in fig. 2(b), where significant joint strength have been recorded with rise in amplitude from 70 to 90.

Fig. 3(a) shows that interaction effect of weld pressure and amplitude. Referring to table 4, the most interactive parameters have recorded as weld time & Amplitude as shown in fig. 3 (b). Which clearly concluded that as weld time is decreasing and amplitude is decreasing joint strength is decreases suddenly.

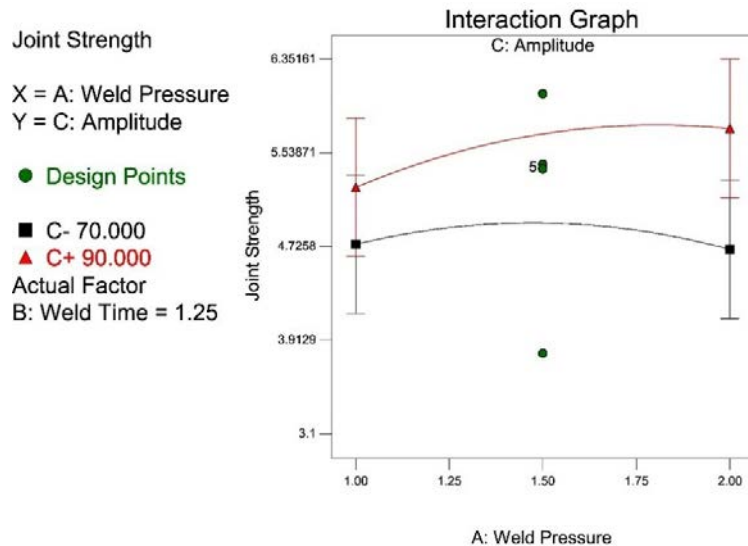


Fig 3 (a): Interactive factor Effect –Weld Pressure & Amplitude

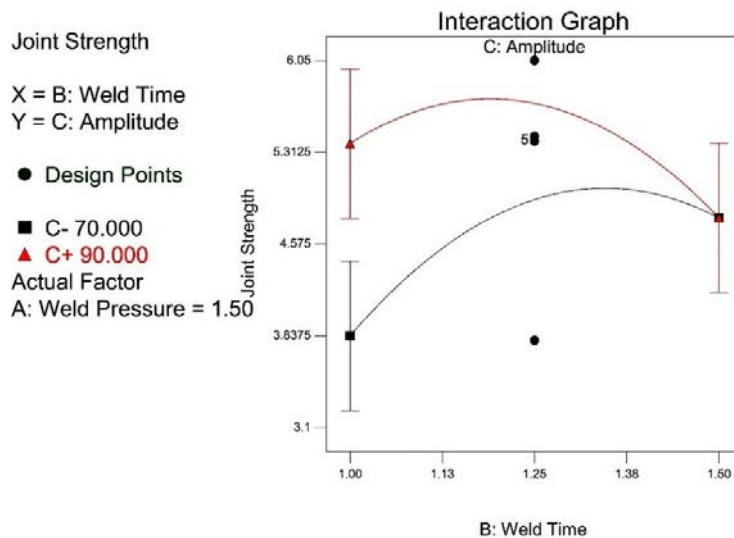


Fig 3 (b): Interactive factor Effect –Weld Time & Amplitude

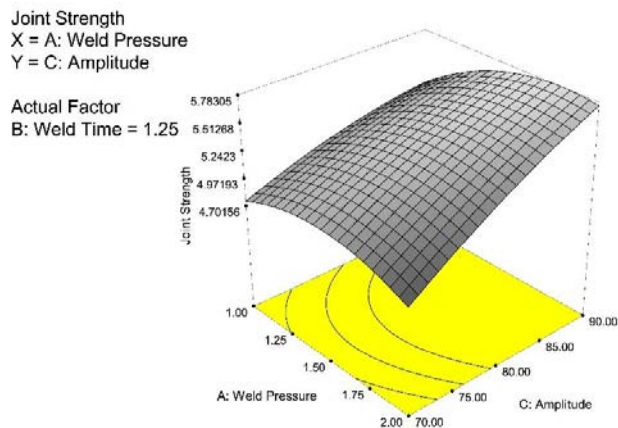


Fig 4 (a): 3D Interactive factor Effect –Weld Pressure & Amplitude

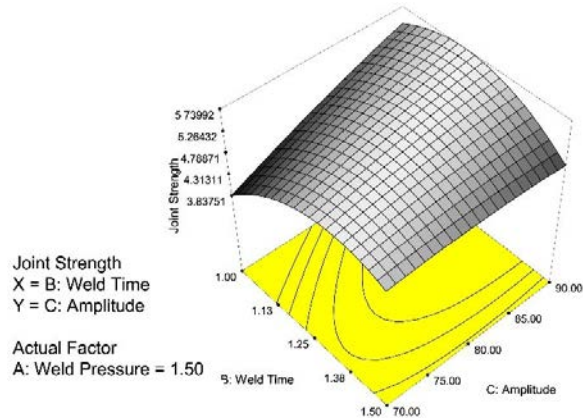


Fig 4 (b): 3D Interactive factor Effect –Weld Time & Amplitude

Fig. 4(a-b) has shown 3D interaction effect of significant interactive parameters shown in fig 3(a-b). Fig. 5 exhibits the relationship between the actual and predicted values of weld strength. These figures also indicate that the developed models are adequate and predicted results are in good agreement with experimental data.

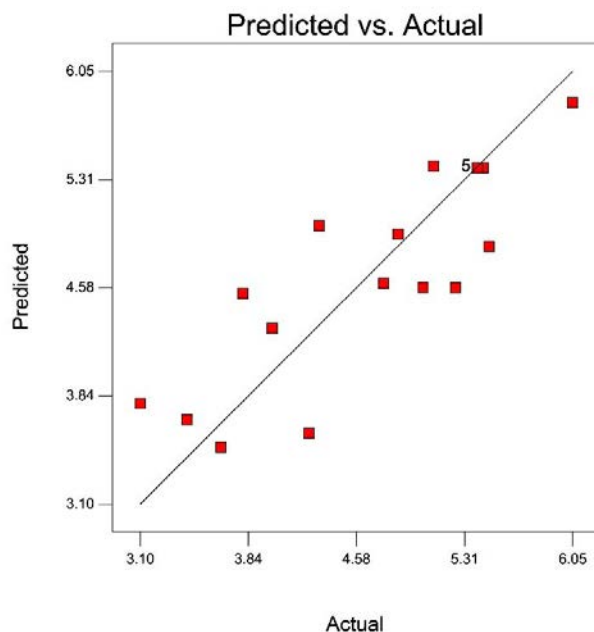


Fig: 5 Graph of actual vs predicted values.

4. Conclusion

In the present paper, experimental investigation of ultrasonic welding process parameter optimization has been performed on ABS as non-metallic material. The following conclusions can be drawn from the experimental investigation carried out within the factor range considered in this study.

- (1) In this study, a second order mathematical model using RSM has revalidated to predict the maximum weld strength of welds produced by USW.
- (2) From the results, it was found that the welding strength mainly depends on value of amplitude and then on amount of weld pressure.
- (3) Beyond 0.3125 bar, the weld strength again start decreasing for constant value of amplitude and weld time. This is because increase in pressure reduces the relative motion between surfaces and that leads to reduced area of contact and so reduced strength.
- (4) Optimized weld strength has observed to be maximum 6.05 MPa at 1.5 bar weld pressure, 1.25 sec weld time and amplitude of 96.82%.

Outcomes of present study have been useful to select optimal welding condition, at which the maximum weld strength can achieve to improve weldability of nonmetallic material and rate of production.

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